Investigation Status Report (June 1999)

EOS Validation Program Investigation:
"Quality Assurance and Stability Reference (QUASAR) Monitoring"

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1. Introduction

A review of the status of Earth observation calibration/validation was completed (Teillet, 1997) and the implications of calibration/validation, stability monitoring, and quality assurance in remote sensing were studied from user market perspectives (Teillet et al., 1997). This led to the current experimental work, a NASA EOS Validation Program project whose objective is to test the feasibility of using single hyperspectral data sets to carry out vicarious calibrations for multiple sensors. The domain of interest and applicability is that of optical sensors with spectral bands in the range encompassed by the reference hyperspectral sensor. The approach is applicable to sensors with large footprints (1-km, for example) and small footprints (20-m, for example). Such a capability has the potential to provide timely monitoring of quality assurance and stability reference (QUASAR) test sites for calibration purposes. The first results from this QUASAR monitoring methodology have been presented by Teillet et al. (1999a, 1999b, 1999c), who used single hyperspectral data sets to generate radiometric calibration estimates for NOAA-14 Advanced Very High Resolution Radiometer (AVHRR), Orbview-2 Sea-viewing Wide-Field-of-view Sensor (SeaWiFS), SPOT-4 Vegetation (VGT), Landsat-5 Thematic Mapper (TM), and SPOT-1/2 Haute résolution visible (HRV). These QUASAR monitoring results are based on data acquisition campaigns at the Railroad Valley playa in Nevada (RVPN) in June 1998 and at the Newell County rangeland site in Alberta (NCRA) in August 1998 and October 1998.

2. The QUASAR Approach

The QUASAR methodology developed by Teillet et al. (1999a) is briefly summarized as follows. Airborne mission and field measurement methodologies have been created to acquire spatially extensive hyperspectral imagery over selected test sites as well as ground-level ancillary and validation data sets. A data processing and analysis scheme has been formulated and implemented to retrieve an average surface reflectance spectrum for the test site under consideration and to predict top-of-atmosphere (TOA) radiances for satellite sensors of interest for calibration monitoring purposes. The Imaging Spectrometer Data Analysis System (ISDAS) at the Canada Centre for Remote Sensing (CCRS) was used to carry out the atmospheric computations using the Modtran-3 radiative transfer code and a look-up table approach (Staenz et al., 1998; Staenz and Williams, 1997). The accuracy of the QUASAR approach is estimated to be on the order of $\pm$ 6 percent (one sigma). A detailed error budget analysis is in progress (Bergeron et al., 1998). The hyperspectral and spatially extensive nature of such benchmark data sets makes it possible to attempt vicarious calibrations for any sensor(s) with appropriate characteristics that imaged the test site on the same day, or within a day or two if atmospheric and surface conditions have not changed significantly. Appropriate sensors include any with footprints that fit comfortably within the test site and with one or more spectral bands encompassed by the wavelength coverage of the airborne hyperspectral sensor.

3. Test Sites and Data Sets

The test sites are located at the Railroad Valley playa in Nevada (RVPN: 38° 28' N, 115° 41' W, 1435 m above sea level (ASL)) and at a flat rangeland area in Newell County, Alberta (NCRA: 50° 18' N, 111° 38' W, 754 m ASL). The playa location has a growing history of international use as a test site for vicarious calibration and it serves as a good setting for the QUASAR methodology proof-of-concept. Rangeland provides slowly varying phenology and relatively uniform vegetation cover over large tracts of land. Given its reasonable proximity to urban areas from which hyperspectral sensors can easily be flown and its lower reflectance compared to desert sites, the NCRA test site has the potential to serve as a routine test site for interim performance monitoring of satellite sensors. Two Alberta rangeland sites were investigated in 1997, one in the Cutbank Creek area on the Saskatchewan-Alberta border and the other in the Newell County area. In both cases, airborne *casi* and ground-based GER3700 data were acquired. After the 1997 measurement campaigns, the two test sites were down-selected to one site for 1998 - the Newell County site was retained (Teillet et al., 1998a). Both the RVPN and NCRA test sites are described in greater detail by Teillet et al. (1999a).

Radiometric uniformity studies were used to determine the location and size of a primary test site in the Railroad Valley and Newell County areas (Teillet et al., 1998b). Image data at 1-km spatial scale were simulated from SPOT HRV imagery in order to characterize radiometric uniformity with the calibration of large footprint sensors in mind. For single-date 1-km images of both the RVPN area and the NCRA area, it was found that there are windows 7 km by 7 km in size that have coefficients of variation less than or equal to 3 percent in all three HRV spectral bands. For a selected prime site of 7 km by 7 km at each location, descriptive statistics from the 1-km data indicate that both sites could be equally useful as vicarious calibration sites for large footprint sensors (Teillet et al., 1998b). These 7 km by 7 km prime test sites were used in the QUASAR studies.

The main results to date were obtained from data acquisition campaigns at the RVPN test site in June 1998 and at the NCRA test site in August and October 1998, which included ground-based measurements, satellite imagery, and airborne hyperspectral data in all cases. The airborne imagery covering each 7 km by 7 km test site was acquired by the Compact Airborne Spectrographic Imager (*casi*). A 100-meter by 100-meter ground validation site within the *casi* data coverage area was selected at each test site for ground-based measurements. These measurements included GER3700™ spectrometer measurements made over the surface and over a Labsphere Spectralon™ reflectance panel to generate surface reflectances for use in validating surface reflectances retrieved from the *casi* imagery (Figure 1). Sun photometer measurements were also made from the centre of the sub-area using a calibrated Microtops-II ™ sunphotometer during the satellite and aircraft sensor overpasses. The resulting data were used to obtain atmospheric aerosol optical depths. At the RVPN test site, the Microtops results were found to be within 0.01 of those obtained using well-calibrated Reagan solar radiometers operated on the same day by the University of Arizona.

4. Data Processing

The main data processing steps are as follows (Teillet et al., 1999a):

1. input hyperspectral flight line image in radiance units;
2. correct flight line image for aircraft roll variations;
3. extract test site coverage segment from flight line image;

4. compute line-averaged scan-angle image for flight line image segment;
5. retrieve surface spectral reflectances from line-averaged scan-angle image;
6. calculate pixel-averaged surface reflectance spectrum for flight line image segment;
7. adjust surface reflectances to nadir view and average solar zenith angle geometry;
8. repeat above processing steps for all flight lines;
9. obtain average surface reflectance spectrum for test site;
10. adjust surface reflectances to sun/view geometry of selected satellite sensor image acquisition;
11. compute TOA radiance spectrum for selected satellite sensor;
12. integrate TOA radiance spectrum over selected satellite sensor spectral band.

It is assumed that the TOA radiance estimates obtained from the QUASAR methodology (i.e., the output of step 12) for the various satellite sensor spectral bands are representative of the entire 7-km by 7-km test site. Thus, digital signal levels (DSL, in counts) can be extracted from relevant satellite sensor images of the test sites and combined with the TOA radiances to generate QUASAR estimates of radiometric calibration gain coefficients in counts per unit radiance. With a reference area of 7 km by 7 km, it is possible to accommodate several image pixels even for large footprint sensors and still stay well within the boundaries of the area to allow for location errors. For comparison, the nominal post-launch calibration coefficients were obtained from the pertinent sources. For NOAA-14 AVHRR, the coefficients are from CSIRO Australia. For the SPOT-1/2 HRVs, SPOT-4 VGT, and Landsat-5 TM, the coefficients were taken from the product tape header and/or documentation. For Orbview-2 SeaWiFS, the calibration is obtained by running the SeaWiFS Data Analysis System (SeaDAS) package.

5. First Results for AVHRR, SeaWiFS, VGT, TM, and HRV

Based on the RVPN data acquisition campaign on June 17, 1998, QUASAR monitoring results were obtained for NOAA-14 AVHRR spectral band 1, Landsat-5 TM spectral bands 1 to 4, and SPOT-1 HRV spectral bands 1 to 3 (cf. Teillet et al., 1999a, for details). The main results consist of *casi*-based TOA radiance predictions and their percentage difference comparisons with satellite image-based TOA radiances determined independently using nominal post-launch calibration coefficients. The QUASAR approach predicts a TOA radiance within 5.1 percent of the nominal NOAA-14 AVHRR calibration on the day of the airborne *casi* data acquisition. Good matches in the range of -2 to -5 percent were also obtained for AVHRR cases on three consecutive days (June 18-20) after the *casi* flight for predominantly forward scattering geometries. QUASAR results for four other AVHRR cases (June 19-22), all with predominantly backward scattering geometries, yielded TOA radiances significantly lower than nominal (differences of –18.3 to –26.2 percent). The reasons for these differences are not yet understood, but they may be due to inadequate corrections for surface reflectance anisotropies. The QUASAR approach yields TOA radiance estimates for SeaWiFS that are in good agreement with nominal values (within 3 percent on average). For VGT, the QUASAR TOA radiance results are significantly lower than nominal (differences of –8.7 to –16.6 percent). These differences are not yet understood, but they are consistent with AVHRR results found for similar scattering geometries. With respect to small footprint sensors, none of the satellite sensor data sets were acquired on the same day as the airborne hyperspectral data acquisition. Therefore, the generation of QUASAR monitoring results in these cases relies exclusively on temporal extrapolations of surface and atmospheric conditions ranging from one to three days. Although good matches in the range of –2 to +3 percent were obtained for TM spectral bands 3 and 4, the RVPN QUASAR data set does not provide a good reference for Landsat-5 TM spectral bands 1 and 2 three days earlier (June 14) because of changes in the playa surface while it was drying after a rainy period earlier in the month. The days following a wet period should be avoided and/or a better knowledge of the RVPN test site's characteristics as a function of time while drying needs to be developed. The QUASAR results for the SPOT-1 HRV spectral bands predict lower TOA radiances than the nominal radiances and hence less sensor degradation (i.e., more counts per unit radiance). For the SPOT-1 HRV case, the one-day signature extension (to June 18) is reasonable since visual observations indicated essentially identical surface and atmospheric conditions and the consistency of the RVPN QUASAR results for AVHRR (forward scattering cases) support this assumption.

Based on the NCRA data acquisition campaign on August 4, 1998, QUASAR monitoring results were obtained for NOAA-14 AVHRR spectral band 1, Landsat-5 TM spectral bands 1 to 4, and SPOT-2 HRV spectral bands 1 to 3 (cf. Teillet et al., 1999a, for details). The main QUASAR result predicts a TOA radiance within 6.3 percent of the nominal NOAA-14 AVHRR calibration on the day of the airborne *casi* data acquisition (August 4). QUASAR results for four other AVHRR cases on subsequent days (August 6, 8, 9, and 10), all with predominantly backward scattering geometries, yielded TOA radiances significantly lower than nominal (differences of –18.3 to –26.2 percent). Again, the reasons for these differences are not yet understood. With respect to small footprint sensor coverage of the NCRA test site, none of the satellite sensor data sets were acquired on the same day as the airborne hyperspectral data acquisitions. For TM data acquired four days after the *casi* data acquisition (August 8), good matches in the range of –1 to –3 percent were obtained for TM spectral bands 2 and 4. QUASAR results for TM spectral bands 1 and 3 predict TOA radiances 8 to 11 percent lower than the radiances based on nominal post-launch calibration. The QUASAR results for SPOT-2 HRV spectral bands predict TOA radiances –11 to –15 percent lower than nominal radiances as well.

6. Work Currently in Progress and Plans for 1999

For the NCRA campaign in August 1998, results for Orbview-2 SeaWiFS and SPOT-4 VGT are currently being generated. For the NCRA campaign in October 1998, results are being generated for NOAA-14 AVHRR, Orbview-2 SeaWiFS, SPOT-4 VGT, SPOT-2 HRV, and Landsat-5 TM. This latter data set is particularly promising because all of the satellite images were acquired on the same day as the *casi* overpass (October 4).

Plans for 1999 data acquisition campaigns remain uncertain. CCRS is not in a position in 1999 to fund a QUASAR data acquisition campaign and the subsequent data processing and analysis. The hope is to work with collaborators at the University of Arizona and possibly NASA/GSFC to acquire a suitable hyperspectral data set, at least at the RVPN test site if not the NCRA test site, to pursue the QUASAR proof-of-concept after the launch of EOS Terra. This would allow an attempt to be made to demonstrate that calibration results based on the QUASAR monitoring methodology can be generated for EOS sensors, particularly Landsat-7 Enhanced Thematic Mapper Plus (ETM+), Terra Moderate Resolution Imaging Spectroradiometer (MODIS), and Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

Figure 1. Surface reflectances retrieved from the *casi* imagery compared to surface reflectances based on GER3700™ spectrometer measurements made over the surface and over a Labsphere Spectralon™ reflectance panel. The ± 2 percent error bars indicate measurement set standard deviations and not measurement uncertainties. The diagonal line is the unity slope line.

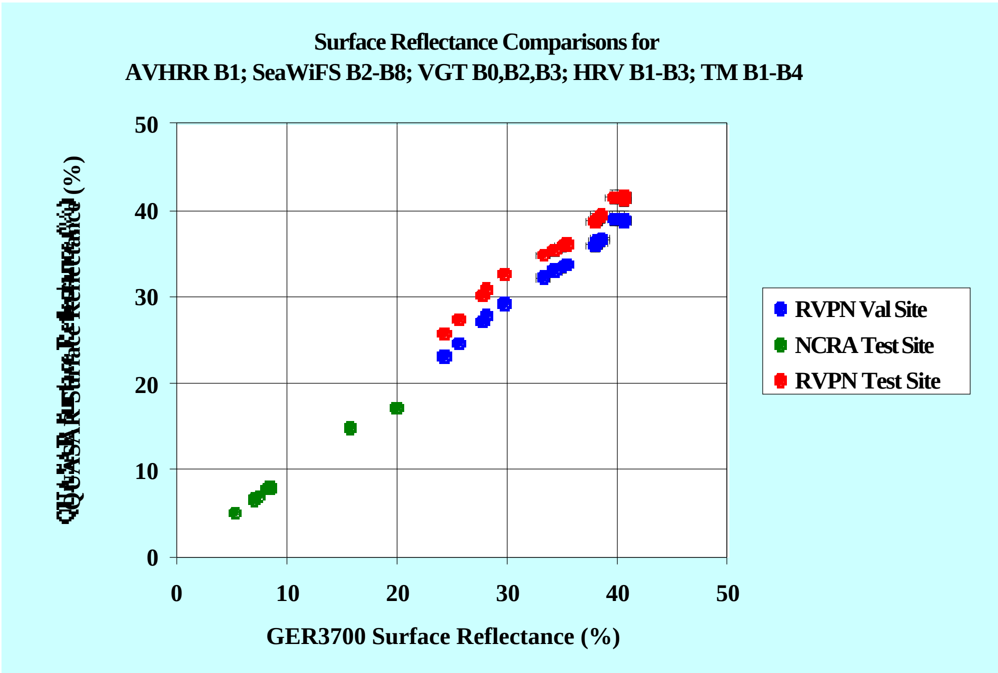
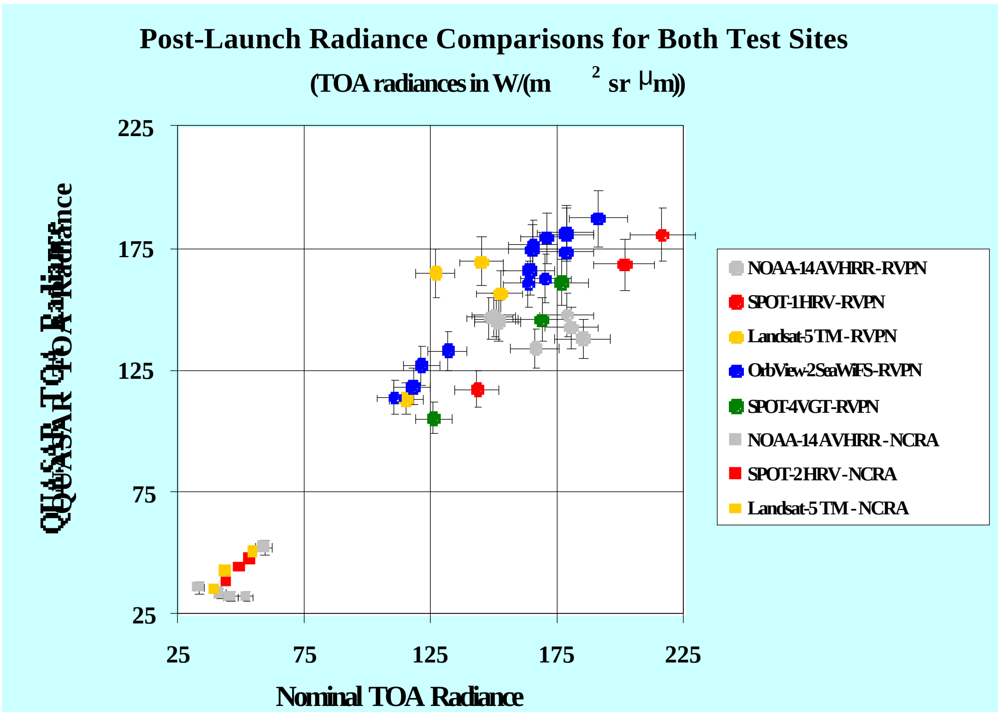


Figure 2. Comparison of top-of-atmosphere (TOA) radiance results for the indicated sensors (for the indicated spectral bands) at the RVPN and NCRA test sites. The error bars represent ± 6 percent uncertainty levels. The diagonal line is the unity slope line.



7. Main Technical Challenge

The main technical challenge facing the QUASAR monitoring methodology as it stands now concerns surface reflectance anisotropies. For both the RVPN and NCRA test sites, there is limited information available on bi-directional reflectance as a function of illumination and viewing angles, and yet this information is needed in data processing steps 7 and 10 mentioned in Section 4 of this report. Step 7 adjusts the surface reflectances retrieved from each flight line segment to allow for the variations in sun angle during airborne data acquisition. Step 10 adjusts the average surface reflectance for the test site to the illumination and viewing geometries pertinent to the satellite sensor case under consideration.

Some view angle measurements were made at both test sites in 1997 using the ground-based GER3700 spectrometer for a limited selection of solar illumination angles. Although these data sets have been helpful, it is not known to what extent they encompass the full range of geometries and temporal and spatial variations that occurred during the QUASAR data acquisition campaigns in 1998. This issue is expected to be more critical in the case of the vegetated NCRA test site than it is for the RVPN test site. Preliminary indications are that bi-directional reflectance factors (BRF) for the NCRA surface based on GER3700 measurement sequences are very similar to results obtained from the Chen-modified Roujean BRF model for a barren land surface (Chen and Cihlar, 1997; Roujean et al., 1992).

8. Collaborations

University of Arizona: collaborators in the development of the QUASAR monitoring approach; collaborators in the QUASAR proof-of-concept for the Nevada playa test site.

Université de Sherbrooke: collaborators in the development of the QUASAR monitoring approach; contracted by CCRS to develop error budget model for the QUASAR approach.

Hyperspectral Data International, Dartmouth, Nova Scotia: contracted by CCRS to acquire and process airborne hyperspectral imagery with the Compact Airborne Spectrographic Imager (CASI).

EOS MODIS Science Team, NASA/GSFC: liaison and information exchange.

CNES, France: collaborators in the QUASAR proof-of-concept for the SPOT-1/2 HRV and SPOT-4 HRVIR and VGT sensors, primarily.

CSIRO, Australia: liaison and information exchange on the use of land test sites for calibration of Earth observation satellite sensors, on the development of hyperspectral Earth observation sensors, and on calibration updates for the NOAA-14 AVHRR.

9. Data Exchange and Archiving

Key benchmark data and vicarious calibration monitoring results will be put on the CCRS Web site in due course

Detailed benchmark data and vicarious calibration monitoring results will likely be made available via CD-ROM

10. Hyperlink

A calibration/validation component of the CCRS Web site has been established.
http://www.ccrs.nrcan.gc.ca/ccrs/tekrd/rd/ana/calval/calhome.html
The QUASAR work will be reported there in due course.

11. Schedule Milestones

1997 Meetings	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
CCRS QUASAR Team Meetings	x	x	x	x	x	x	x	x	x	x	x	x
MODIS Science Team Meeting					x							
Canadian Cal/Val Workshop					x							
Ottawa Meeting (U. Sherbrooke)					x							
Tucson Meeting (U. Arizona)										x		
MODIS Science Team Meeting										x		
EOS Validation Meeting												x
1998 Meetings	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
CCRS QUASAR Team Meetings	x	x	x	x	x	x	x	x	x	x	x	x
CCRS Project Review	x											x
Sherbrooke Meeting (U.Sherbrooke)			x									
Canadian Cal/Val Workshop					x							
Ottawa Meeting (U.Arizona)					x							
MODIS Science Team Meeting						x						
Ottawa Meeting (CCRS/U. Sherbrooke)									x			
Tucson meeting (U.Arizona/CCRS)										x		
Sherbrooke Mtg (U.Sherbrooke/CCRS)											x	
MODIS Science Team Meeting												x
1999 Meetings (as of 1999-06-04)	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
CCRS QUASAR Team Meetings	x	x	x	x	x	x	?	?	?	?	?	?
Ottawa Meeting (CCRS/U. Sherbrooke)			x									
Tucson meeting (U.Arizona/CCRS)			x									
MODIS Science Team Meeting				x								
CCRS Project Review						x						
MODIS Science Team Meeting								?				
Sherbrooke Mtg (U.Sherbrooke/CCRS)									?			
Canadian Cal/Val Workshop											?	

1997 Data Acquisition	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Nevada campaign						x						
Alberta (NCRA) campaign							x					
Alberta (Cutbank Creek) campaign							x					
1998 Data Acquisition	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Alberta (NCRA) campaign					x							
Nevada (RVPN) campaign						x						
Alberta (NCRA) campaign								x				
Alberta (NCRA) campaign										x		
1999 Data Acquisition	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Alberta (NCRA) campaign										?		
Nevada (RVPN) campaign										?		

12. QUASAR Publications

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Teillet, P.M., G. Fedosejevs, R.P. Gauthier, N.T. O'Neill, M. Bergeron, K.J. Thome, S.F. Biggar, H. Ripley, and A. Meygret, 1999b, "Radiometric Calibration of Multiple Earth Observation Sensors Using Hyperspectral Data", *Proceedings of the Fourth International Airborne Remote Sensing Conference and Exhibition and the Twenty-First Canadian Symposium on Remote Sensing*, Ottawa, Ontario, in press.

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13. Other References

Chen, J.M., and Cihlar, J., 1997. "A Hotspot Function in a Simple Bidirectional Reflectance Model for Satellite Applications", *Journal of Geophysical Research*, 102(D22):25907-25913.

Roujean, J.-L., Leroy, M.J., and Deschamps, P.-Y., 1992. "A Bidirectional Reflectance Model of the Earth's Surface for the Correction of Remote Sensing Data", *Journal of Geophysical Research*, 98:20455-20468.

Staenz, K., and Williams, D.J., 1997. "Retrieval of Surface Reflectance from Hyperspectral Data Using a Look-up Table Approach", *Canadian Journal of Remote Sensing*, 23(4):354-368.

Staenz, K., Szeredi, T., and Schwarz, J., 1998. "ISDAS – A System for Processing/Analyzing Hyperspectral Data", *Canadian Journal of Remote Sensing*, 24(2):99-113.